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NAVORD REPORT 4345

FC

A HYPERVELOCITY GUN USING A SHOCK-COMPRESSED STEAM-HEATED PROPELLANT

30 JULY 1956

U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

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NAVORD Report 4345

Aeroballistic Research Report 351

A HYPERVELOCITY GUN USING A SHOCK-COMPRESSED STEAM-HEATED PROPELLANT

Prepared by:

A. E. Seigel and Z. I. Slawsky

ABSTRACT: This report describes a new type of hypervelocity gas gun for launching models of hypersonic missiles. The basic principle of this launcher (called the NOL Shock Gun) is the advantageous use of a chemical reaction (oxygen plus hydrogen added to helium) to produce a low molecular weight high temperature propellant gas and a shock to further compress and heat the hot steam-helium mixture. As described in the report the NOL Hypervelocity Gun is modified by the elongation of the gun chamber and the addition of the shock producing chamber in back of it. The paper contains theoretical analysis of the expected performance of this gun and discusses the use of the same principle for shock tubes where extreme high velocity is desired.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NAVORD Report 4345 30 July 1956

This report contains a description of a new type of hypervelocity missile launcher, a theoretical analysis of its performance and an outline of the method of converting the NOL Hypervelocity Gun to the new type. This conception of a new hypervelocity gun resulted from the need of devising means of launching models of Fleet Ballistic Missiles at speeds which are equal to those of the actual missile.

Although this gun was actually conceived and developed during the past year, it is in a sense the end product of over six years of research in the field of interior ballistics. The authors wish therefore to acknowledge their appreciation for the support received during this period to the Armaments Branch of the Office of Naval Research and Re5-a of the Bureau of Ordnance for supporting the initial stages of hypervelocity gun research, to Re3-1 of the Bureau of Ordnance for assistance in the construction of the steam-helium hypervelocity gun, and finally to the Special Projects Office of the Bureau of Ordnance for the high priority backing which made it possible to design and fire this gun in six months.

The authors also wish to acknowledge their debt to Dr. Hermann Kurzweg, Associate Technical Director for Aeroballistic Research for his enthusiastic support of a scheme in the stages where its final results were still in question.

WILLIAM W. WILBOURNE
Captain, USN
Commander

H. H. KURZWEG, Associate Technical
Director for Aeroballistic Research
By direction

CONTENTS

ILLUSTRATIONS

LIST OF SYMBOLS

a	Sound velocity of gas
$\overline{C}_v$	Average specific heat per unit weight if no dissociation
D	Dissociation energy of water, per mole of water, divided by the molecular weight of mixture
D_1	Gun chamber diameter
D_o	Shock chamber diameter
e	Internal energy of gas per unit weight
M	Mach number of gas
n	Exponent in isentropic relation for maximum dissociated gas
N	Number of moles of constituents in dissociated gas
N_o	Number of moles of constituents in undissociated gas
P	Pressure of gas
R	Gas constant of gas per unit weight
s	Entropy of gas per unit weight
S_1	Denotes shock which is initially propagated into gun chamber
S_2	Denotes shock which is reflected at the end of the gun chamber and travels back toward the shock chamber
T	Temperature of gas
u	Velocity of gas
v	Specific volume of gas
X_{gc}/X_{sc}	Ratio of gun chamber length to shock chamber length
γ	Specific heat ratio of gas (here equal to 1.5)
ϵ	Equal to $N - N_o$

ρ	Density of gas
σ	Riemann function, defined in Appendix I

SUBSCRIPTS

o	Denotes initial state of gas in shock chamber after chemical reaction
1	Denotes initial state of gas in gun chamber after chemical reaction
2	Denotes state of gas between contact surface and shock S_1
3	Denotes state of stationary gas behind shock S_3
s	Denotes state of gas in the shock chamber just before the change in area section
g	Denotes the state of gas in the gun chamber just after the change in area section
A	Denotes state of gas in shock chamber before chemical reaction
B	Denotes state of gas in gun chamber before chemical reaction

BARRED QUANTITIES

A bar over a quantity in Appendix I denotes that it is dimensionless

A HYPERVELOCITY GUN USING A SHOCK-COMPRESSED STEAM-HEATED PROPELLANT

INTRODUCTION

1. The quest for high-speed model launchers dates back at least a dozen years. The first successful high velocity launcher for small caliber projectiles was developed by the New Mexico School of Mines, and since then this type of gun has been improved by Dr. Charters of the Ames Aeronautical Laboratory of NACA and a similar one built by the Universal Winding Company for the Ballistics Research Laboratory, Aberdeen Proving Ground.

2. More recently the Naval Ordnance Laboratory has developed the "NOL Hypervelocity Gun", the 40-mm size of which is capable of launching models at speeds almost as high as those reached by the small caliber guns. This gun is described in references (a) and (e). Figure 1 illustrates the performance of this gun. There exists also an NOL Hypervelocity Gun in the caliber 0.50 size.

THE BASIC PRINCIPLE OF HIGH SPEED GUNS

3. The basic principle of all high-speed gas guns is the use of a low acoustic impedance gas, the idea being to get the required pressure in the chamber with the smallest weight of propellant gas per unit volume. There are two main methods for obtaining a low molecular weight, high temperature gas, i.e., one with a low acoustic impedance. One of these has already been amply discussed in the literature. It depends upon the use of a single stroke piston to compress and adiabatically heat the light gas. The other is the method used here at NOL in its Hypervelocity Gun. Chemical energy is used to heat helium without adding too much of the heavy components which supply the chemical energy. More specifically, oxygen and hydrogen are added to the helium in the ratio of 1:3:8 by molar volume. The hydrogen-oxygen reaction furnishes the necessary energy,* (see references (a) and (e)).

- -

*It is to be noted that the helium can be supplanted in part or in total by hydrogen, yielding slightly higher projectile velocities and lower mixture temperatures. However, in this case the danger of hydrogen embrittlement and explosion must be recognized.

4. The NOL Hypervelocity Gun has a muzzle velocity capability which is less than an equivalent gun system using the compression principle. This is due to the fact that the amount of chemical energy that can be used is limited, whereas the temperature that can be obtained by the alternate method depends only on the compression ratio. The advantage of the NOL Hypervelocity Gun lies in the simplicity of its construction with the practicability of making large guns using the same principle. The compression ratio required by the other type of gun makes the chamber impractically large for guns above the 20-mm size.

5. The following scheme, the "shock gun" scheme, has been conceived by the authors in order to achieve even lower acoustic impedance and hence higher muzzle velocity without resorting to moving pistons or very large compression ratios.

THE SHOCK GUN PRINCIPLE

6. The basic principle in the shock-compressed steam-helium ("shock gun") method is the advantageous use of the chemical reaction as already used in the NOL Hypervelocity Gun together with the advantages of heating by compression. The first carries with it the penalty of increase in molecular weight due to the combustion products. The second does not require any such contamination but it does require large initial volumes. In the "shock gun" a hot gas is raised in pressure and temperature still further by means of a compression. The compression is effected by the use of a shock rather than a mechanical piston. The obvious advantage of this procedure is that one does not have any moving parts in the chamber of the gun. Consideration was given to the possibility of compressing the steam-helium mixture with a piston, but it was rejected in favor of the method to be described below.

7. The fabrication of the "shock gun" from an existing gun and an adapter is schematically illustrated in Figure 2. The uppermost sketch is a schematic of the existing caliber 0.50 gun (one of the NOL Hypervelocity Guns) with its 30-mm chamber. Immediately below it is a sketch of an adapter containing a 30-mm diameter chamber and a 70-mm diameter chamber. The latter chamber will be referred to as the shock-producing chamber or shock chamber for short and the first as part of the gun chamber. Below this in the same figure is a sketch of the assembled "shock gun". As can be seen in the assembly sketch the gun chamber is sealed from the gun barrel by a diaphragm identical to the ones used in the caliber 0.50 NOL Hypervelocity Gun. (This type of diaphragm developed at NOL,

reference (a), upon rupture simply folds, and no pieces of the diaphragm are sent downstream.) The shock chamber is sealed from the gun chamber by another diaphragm identical to those used in the 40-mm NOL Hypervelocity Gun. In fact the breech plug, although somewhat shorter is essentially the same as that used in the 40-mm NOL Hypervelocity Gun.

8. The conceived method of operation is illustrated in Figure 3. Diagram A shows the "shock gun", the gun chamber of which is loaded with oxygen-hydrogen-helium mixture (the same mixture as used in the NOL Hypervelocity Gun) to a pressure P_B of about 850 psi. The shock chamber is loaded with the same mixture to a pressure P_A of 8000 psi. The mixture in the gun chamber is now ignited. The reaction will raise the pressure to approximately 7500 psi and a temperature of approximately 2700°K. Since the diaphragms are designed to take much higher pressure, this will result in what is known in gun terminology as a "hangfire" in the gun chamber. Diagram B indicates the new state. After a short time delay of approximately 1 to 2 milliseconds, the mixture in the shock chamber is ignited raising the pressure in it to an estimated 45,000 psi and a temperature approximately the same as in the gun chamber (see Diagram C). The pressure in the shock chamber is now sufficient to rupture the chamber diaphragm and to fold it so that it is out of the way of the flow (see Diagram D). A shock S_1 as is shown in D is propagated into the gun chamber by the gas expanding from the shock chamber. The shock will be reflected at the end of the gun chamber as is indicated in E, further raising the pressure and temperature to values P_3 and T_3. The strength of the reflected shock will, of course, depend on the rupture process of the gun diaphragm which divides the gun chamber from the missile. For the calculations presented below, reflection has been assumed to be complete. The effect of incomplete reflection will be discussed later.

9. Figure 4 is a graphical presentation of the pressure ratio P_3/P_0 as a function of the initial pressure ratio P_0/P_1 across the diaphragm separating the shock chamber from the gun chamber. As is shown in the figure, curves have been calculated for a series of shock chamber to gun chamber diameter ratios. Appendix I describes the method used for these calculations. The curve appropriate to the gun under discussion is one slightly above that labeled $D_0/D_1 = 2$. Since the initial pressure ratio is approximately 6 for the conditions described above, a 20% gain in pressure over that in the shock chamber is expected. This would make the pressure that the missile first feels approximately 55,000 psi. Figure 5 is a graphical presentation of the resulting sound speed ratio, a_3/a_0 as a

function of the initial pressure ratios. Again, separate curves are calculated for the various ratios of shock chamber to gun chamber diameters. The curve corresponding to the gun under discussion is again one slightly above that labeled 2. Notice that for a pressure ratio of six the expected sound speed will be somewhat more than 1.4 times the sound speed already in the steam-helium mixture. Since the sound speed in the steam-helium mixture is approximately 7000 ft/sec it is expected that after shock reflection the sound speed will be approximately 10,000 ft/sec.

10. Figure 6 is a graphical presentation of the density ρ_1 before any shock has been propagated through the gun chamber divided by the density ρ_3 after shock reflection as a function of the initial pressure ratio. Again for an initial pressure ratio of six the increase in density will be approximately 3-1/2 times the initial density. This means that the effective gun chamber length will be 0.275 times its initial length. This loss in effective chamber volume is the price paid for the increase in the sound speed by the method of shock heating and compression. The length of gun chamber required is determined by the methods outlined in reference (c).

11. The necessary length of gun chamber relative to the length of shock chamber is determined by the condition that the reflected shock S_2 reach the contact surface at the same time as the first reflected rarefaction disturbance (dashed line A-B in Appendix I). This length ratio is plotted as a function of P_0/P_1 in Figure 7.

12. Figure 8 contains four calculated performance curves giving the muzzle velocity as a function of the in-gun-weight of projectile. These curves are calculated on the basis of a 40-mm, 4-meter long gun barrel with initial pressure experienced by the projectile of 40,000 psi. (See references (b) and (c) for method of calculation.) The curves correspond to different sound speeds. Conversion to a caliber 0.50 gun, 50 inches long is straightforward. The corresponding missile weight must be in the ratio of the diameters raised to the third power. Thus 40 grams in this gun corresponds to 1.25 grams in the caliber 0.50. Increase in initial pressure can also be taken into account by the condition that the muzzle velocity will be the same as long as $\frac{PAL}{M}$ is kept the same. P is the initial pressure behind the projectile, A the area, L the length of travel, and M the mass of the projectile. Thus 55,000 psi corresponds to a mass of 40 x 40/55 or approximately 30 grams. According to these calculations therefore it is expected that a nylon sphere (1.25 grams--equivalent to 40

grams in the 40-mm gun) will be launched at somewhere between 15,000 and 16,000 ft/sec. The formulae used in calculating Figures 4 through 7 are presented in Appendix I. In these calculations the final state of the steam-helium mixture has been assumed to follow ideal gas laws without dissociation of the water molecule. The effect of dissociation is discussed in Appendix II. It is shown there that the muzzle velocity is not appreciably affected by the occurrence of dissociation. For this reason it was thought not worthwhile to carry through more exact calculation of the projectiles motion with the dissociation taken into account.

SUMMARY AND CONCLUSION

13. It is our opinion that there are several factors which make this gun scheme attractive.

(a) Because the reaction in the gun chamber is contained. it will go to completion, and the resulting pressure and temperature will be higher than that attained in the NOL Hypervelocity Gun.

(b) Since the diaphragm separating the shock chamber from the gun chamber will have 7500 psi on the downstream side (gun chamber side), rupture should not take place until the pressure in the shock chamber exceeds 20,000 psi (diaphragm used here ruptures at 12,500 psi). Since the higher the pressure prior to rupture the more complete is the combustion, better performance should be obtained from the shock chamber too.

(c) Since the shock is used to further heat and compress an already hot mixture of steam and helium, the volume ratio required (initial volume to final volume) to reach a temperature of 5000°K is less than four. Because of this the shock chamber and gun chamber will not be impractically large: for example, a 200 caliber 40-mm gun would require a gun chamber 4 meters long and a shock chamber about 1 meter long, an overall length of 13 meters or approximately 40 feet. This is not much longer than the caliber 0.50 New Mexico School of Mines type of gun.

(d) In the calculations, complete reflection of the shock was assumed. If the diaphragm separating the gun barrel from the gun chamber, ruptures as the shock hits it, the reflection will not be complete. An estimate of the effect of incomplete reflection on the muzzle velocity can be made as follows: the limiting case will be one with no reflection at all. It is then not too difficult to calculate the approximate projectile motion when accelerated by a gas at pressure P_2 and with a velocity U_2 (contact surface velocity). It turns out that the loss in pressure and temperature due to the fact that the flow is not brought to rest is nearly compensated for by the fact that the propelling gas is already in motion.

14. The application of this principle, that is the multi-stage compression chamber using a steam-helium mixture to shock tube drivers, is obvious. Although the idea of the use of a series of compression chambers in a shock tube each having higher pressure than the previous one is not new, the use of a hot steam-helium mixture initially in each of the compression chambers is. The difference in the expected performance between this scheme and the previous ones is large. Quantitative evaluation will appear in a future publication.

15. Finally it is to be noticed that although the shock gun scheme uses two stages it is possible to introduce a third and a fourth stage thus raising the temperature. However, in the opinion of the authors there are several practical arguments which make the introduction of other stages not particularly attractive. Larger chambers will be necessary, and the higher temperature will aggravate the erosion problem and the heat loss due to radiation.

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(b) Seigel, A. E., "The Effect of the Optimum Chambrage on the Muzzle Velocity of Guns with a Qualitative Description of the Fundamental Phenomena Occurring During Gun Firing", NAVORD Report 2691, Oct 1952

(c) Seigel, A. E., "The Influence of Chamber Diameter on the Muzzle Velocity of a Gun with an Effectively Infinite Length Chamber", NAVORD Report 3635, Jan 1954

(d) Lukasiewicz, J., "Shock Tube Theory and Applications", National Aeronautical Establishment, Canada, Report No. 15

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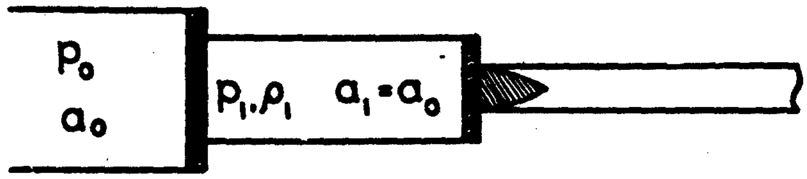
APPENDIX I

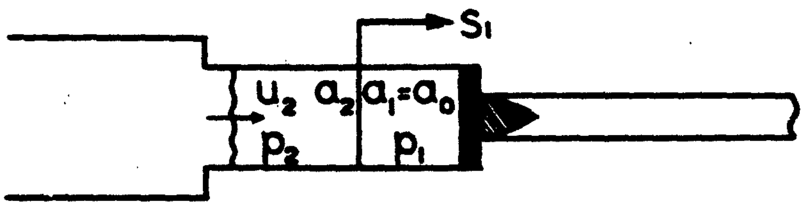
EQUATIONS USED TO CALCULATE PRESSURE RATIO (P_3/P_0) AND SOUND VELOCITY RATIO (a_3/a_0) AFTER PASSAGE OF REFLECTED SHOCK

1. The history of the gases in the shock chamber and the gun chamber after each has been ignited may be obtained from conventional chambered shock tube theory (for example, see report by J. Lukasiewicz, reference (d)). The states of the gases after ignition are depicted in the sketch below,



where P_0 is the pressure of the gas in the shock chamber and P_1 is the relatively lower pressure of the gas in the gun chamber. Both gases have equal sound velocities, since the same proportion of the constituents of the gaseous mixture before ignition are in each of the chambers.* Thus, $a_0 = a_1$.

2. The difference in pressure, $P_0 - P_1$, is sufficient to rupture the diaphragm separating the gun chamber from the



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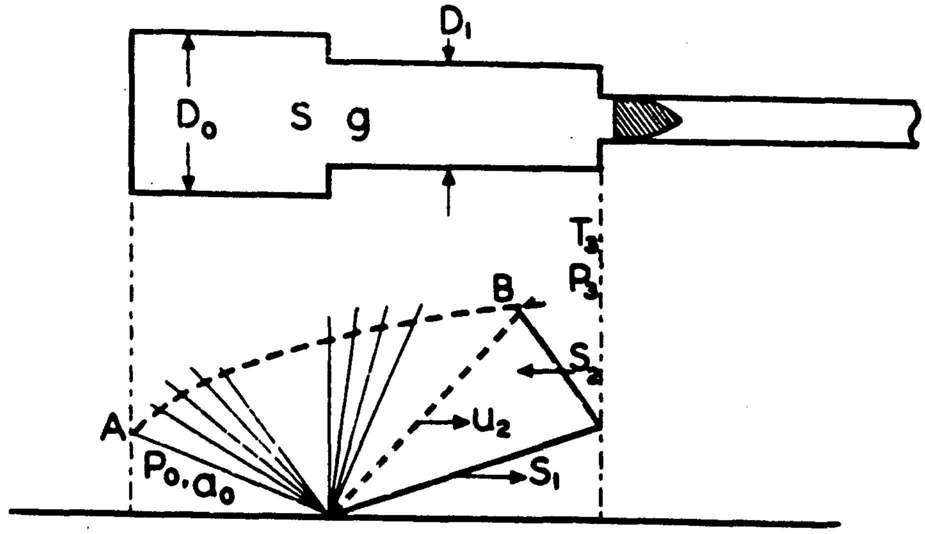
* The mixture before and hence after ignition are at different pressures, but the effect of pressure on the adiabatic flame temperature and sound velocity is assumed negligible.

shock chamber; the gas from the shock chamber rushes into the gun chamber pushing the gas in the gun chamber at a velocity U_2; this pushing causes a shock to be sent ahead into the gas in the gun chamber at a greater velocity S_1. This shock increases the pressure and sound velocity of the gas it passes through to values denoted by P_2 and a_2 respectively.

3. When the shock reaches the end of the gun chamber it is reflected and travels back toward the shock chamber with velocity S_2 raising the pressure and sound velocity of the gas it travels through to P_3 and a_3.

4. The travel-time diagram is sketched below:



5. The equations describing the changes which take place are summarized below in a dimensionless form. The quantities are made dimensionless by the following transformations:

$$\bar{u} = \frac{u}{\frac{2}{\gamma-1}a_0} \qquad \bar{\sigma} = \frac{\sigma}{\frac{2}{\gamma-1}a_0} \qquad \bar{a} = \frac{a}{\frac{2}{\gamma-1}a_0}$$

$$\bar{p} = p/p_0$$

where σ is the Riemann function equal to $\int_0^p \left(\frac{dP}{a\rho}\right)_s$. For a perfect gas

$$\bar{\sigma} = \frac{2\bar{a}}{\gamma-1}$$

$$\bar{p} = \bar{\sigma}^{2\gamma/(\gamma-1)} \qquad (1)$$

The suffix "s" is used to denote the state of the gas in the shock chamber just before the change of area section; the suffix "g" is used to denote the state of the gas in the gun chamber immediately after the change of area section.

Shock Chamber Equations

$$\bar{u}_s + \bar{\sigma}_s = 1 \qquad \text{(rarefaction equation)} \qquad (2)$$

Change of Area Section Equations

$$\frac{2}{\gamma-1}\bar{u}_s^2 + \bar{\sigma}_s^2 = \frac{2}{\gamma-1}\bar{u}_g^2 + \bar{\sigma}_g^2 \qquad \text{(energy equation)} \qquad (3)$$

$$\frac{\pi}{4}D_0^2(\bar{\sigma}_s)^{\frac{2}{\gamma-1}}\bar{u}_s = \frac{\pi}{4}D_1^2(\bar{\sigma}_g)^{\frac{2}{\gamma-1}}\bar{u}_g \qquad \text{(continuity equation)} \qquad (4)$$

6. The maximum velocity attainable in the throat state "g" is sonic; at this time

$$\bar{u}_g = \bar{u}_g^* = \bar{a}_g^* = \bar{\sigma}_g^*\left(\frac{\gamma-1}{2}\right) \qquad (5)$$

where the asterisk indicates the sonic conditions. When the sonic condition occurs equation (5) is used with equations (3) and (4).

Equation Relating Gas in State "g" With the Gas Behind Shock

$$\bar{u}_g + \bar{\sigma}_g = \bar{u}_2 + \bar{\sigma}_2 \qquad \text{(rarefaction equation)} \qquad (6)$$

Equations for States Across Shocks

$$\bar{u}_2 = \frac{u_2}{\frac{2}{\gamma-1}a_0} = \frac{u_2}{\frac{2}{\gamma-1}a_1} = \frac{P_2/P_1 - 1}{\sqrt{\frac{2\gamma}{\gamma-1}\left[\frac{\gamma+1}{\gamma-1}\cdot P_2/P_1 + 1\right]}} \qquad (7)$$

$$\frac{a_2}{a_0} = \frac{a_2}{a_1} = \sqrt{\frac{\frac{\gamma+1}{\gamma-1} + P_2/P_1}{\frac{\gamma+1}{\gamma-1} + P_1/P_2}} \qquad (8)$$

$$P_3/P_2 = \frac{\left(\frac{\gamma+1}{\gamma-1} + 2\right)\left(P_2/P_1\right) - 1}{P_2/P_1 + \frac{\gamma+1}{\gamma-1}} \qquad (9)$$

$$\frac{a_2}{a_0} = \left[\frac{P_3/P_2\left(\frac{\gamma+1}{\gamma-1} + P_3/P_2\right)}{\left(\frac{\gamma+1}{\gamma-1}\right)P_3/P_2 + 1}\right]^{1/2} \qquad (10)$$

7. From equations (1) through (10), the desired quantities P_3/P_0, and a_3/a_0 can be obtained as a function of P_0/P_1. In the present instance the computations were done with an automatic computing machine, an IBM 650 computer, by the Applied Mathematics Division, Aeroballistic Research Department of NOL. The ratio ρ_1/ρ_3 was calculated from the relation:

$$\frac{\rho_1}{\rho_3} = \frac{T_3 P_1}{T_1 P_1} = \frac{T_3 P_1}{T_0 P_1} = \left(\frac{a_3}{a_0}\right)^2 \frac{P_1}{P_3}$$

APPENDIX II

EFFECT OF DISSOCIATION OF WATER IN THE MIXTURE ON THE PROJECTILE VELOCITY

1. In the calculation of projectile velocity the gas mixture was assumed to consist of undissociated products of the reaction (i.e., $2H_2O + H_2 + 8H_e$ with a $\gamma = 1.5$). Actually, of course the water will dissociate as the temperature rises. This is shown in Figure 9 where the percent of dissociation of the water for the mixture is plotted as a function of pressure for constant temperatures. (These curves were calculated on the assumption that the water dissociates into H_2, O_2 and OH.)

2. To determine the effects of the dissociation on the shock gun performance a limiting case of maximum dissociation was examined in which most of the energy imparted to the gas above 4000°K goes toward dissociating the water, while a negligible amount goes toward raising its temperature.* Thus, from the expression for internal energy per unit weight of the gas with dissociation

$$e = \left(1 + \frac{\epsilon}{N_0}\right)\bar{C}_v T + \frac{2\epsilon}{N_0} D \qquad ** \qquad (1)$$

the change in internal energy becomes

$$de = (\bar{C}_v T + 2D)\frac{d\epsilon}{N_0} \qquad (2)$$

where the dT term has been neglected by our assumption of a limiting case of maximum dissociation.

3. From the equation of state of the dissociating gas

$$pv = \frac{N}{N_0}RT = \left(1 + \frac{\epsilon}{N_0}\right)RT \qquad (3)$$

- -

* A more exact calculation is possible but was not attempted because it was thought not worthwhile.

** See list of symbols

and from the Gibbs relation

$$Tds = de + pdv \tag{4}$$

the isentropic relation is obtained as

$$pv^n = \text{constant} \tag{5}$$

with

$$n = 1 + \frac{RT}{2D + C_v T}$$

and in which T has been taken as effectively constant in the derivation in accord with our limiting case assumption. The exponent "n" in equation (5), which can be interpreted as an effective ratio of specific heat, has a value for the mixture at 4000°K of approximately 1.07.

4. From (5) the sound velocity is obtained as

$$a = \sqrt{npv} \tag{6}$$

Further, from the above equations the relations between variables across a normal shock may be easily obtained. It is found that the ratios of p, ρ, a, u , and M across a normal shock are the same function of initial Mach number in this limiting case as for the classic case of an ideal gas.

5. If the conditions of the gas are calculated after the reflected shock passes through it, the pressure is found to rise from 22,500 psi to 44,500 psi and the sound velocity from 8540 ft/sec to 8730 ft/sec. These values are compared to those obtained with the undissociated $\gamma = 1.5$ gas in the table below.

Comparison of State of Gas After Passage of Reflected Shock in Limiting Cases

	Undissociated Gas $\gamma = 1.5$	Maximum Dissociated Gas $\gamma = 1.07$
P_3, psi	55,500	44,500
a_3, ft/sec	10,025	8,730
T_3, °K	5,525	4,000
% Dissociation	0	55%

6. With the conditions in state "3" taken as initial conditions the projectile velocity can be calculated for the

maximum dissociated gas case. For this calculation the gas is taken to expand from state "3" with an effective "γ" of 1.07 until reassociation is complete (i.e., $\epsilon = 0$), after which the gas expands with a γ of 1.50. For the example cited in the text (40 gram projectile in a 40-mm gun), the calculated projectile velocities are compared below.

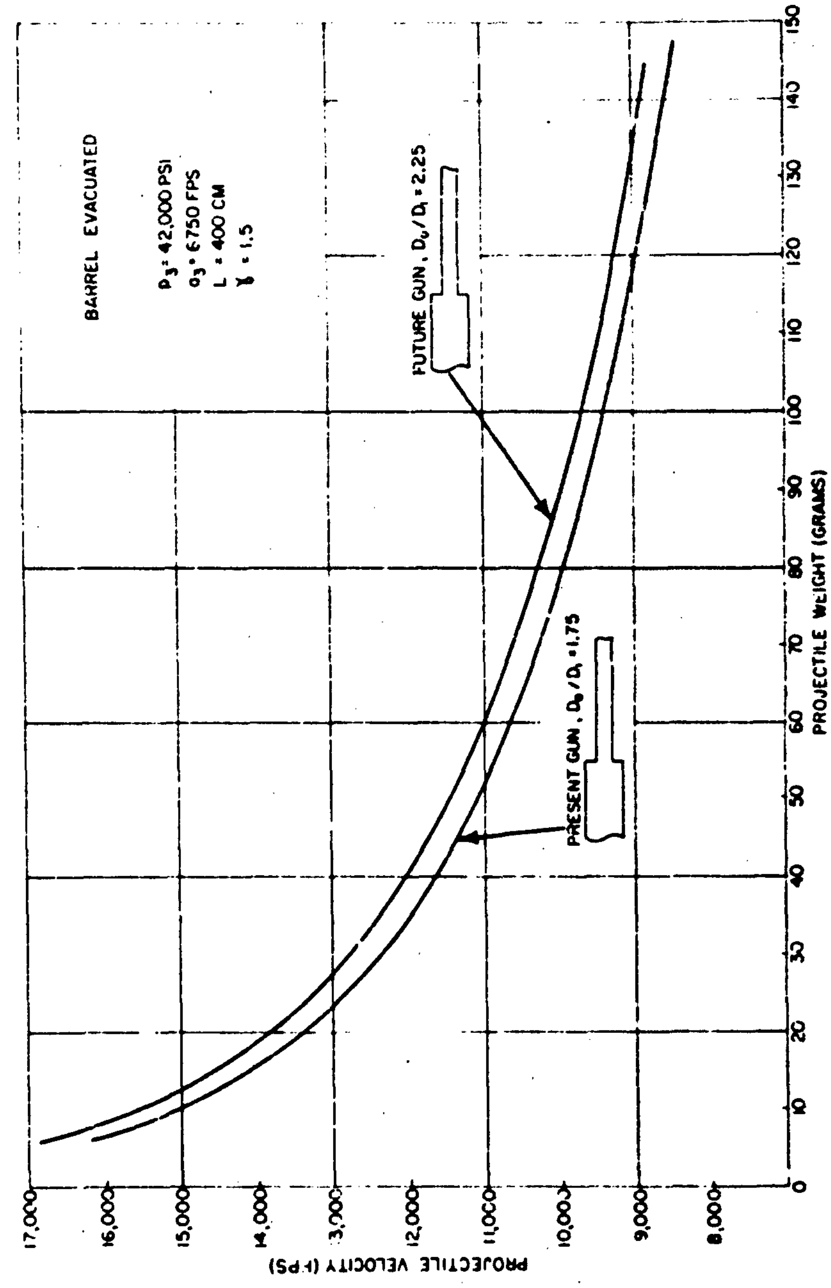
Comparison of Projectile Velocities in Limiting Cases

	Undissociated Gas $\gamma = 1.5$	Maximum Dissociated Gas in State "3", Reassociation During Expansion
Projectile Velocity ft/sec	15,800	15,000

Thus in the extreme case of maximum dissociation the projectile velocity is slightly decreased.

7. Actually from Figure 9 and a knowledge of the specific heats it may be readily shown that the assumption of no dissociation is more nearly correct. Thus, it was calculated that instead of 5500°K, the value of T_3, obtained for the undissociated case, the temperature would drop to about 5000°K.

8. Therefore, because (a) dissociation has little effect on the performance of the shock gun, (b) the gas is more nearly undissociated, and (c) the calculation is considerably simplified, the piston motion was computed with the assumption that no dissociation occurs.



THE NOL HYPERVELOCITY GUN

FIG. I 40 MM GUN PERFORMANCE

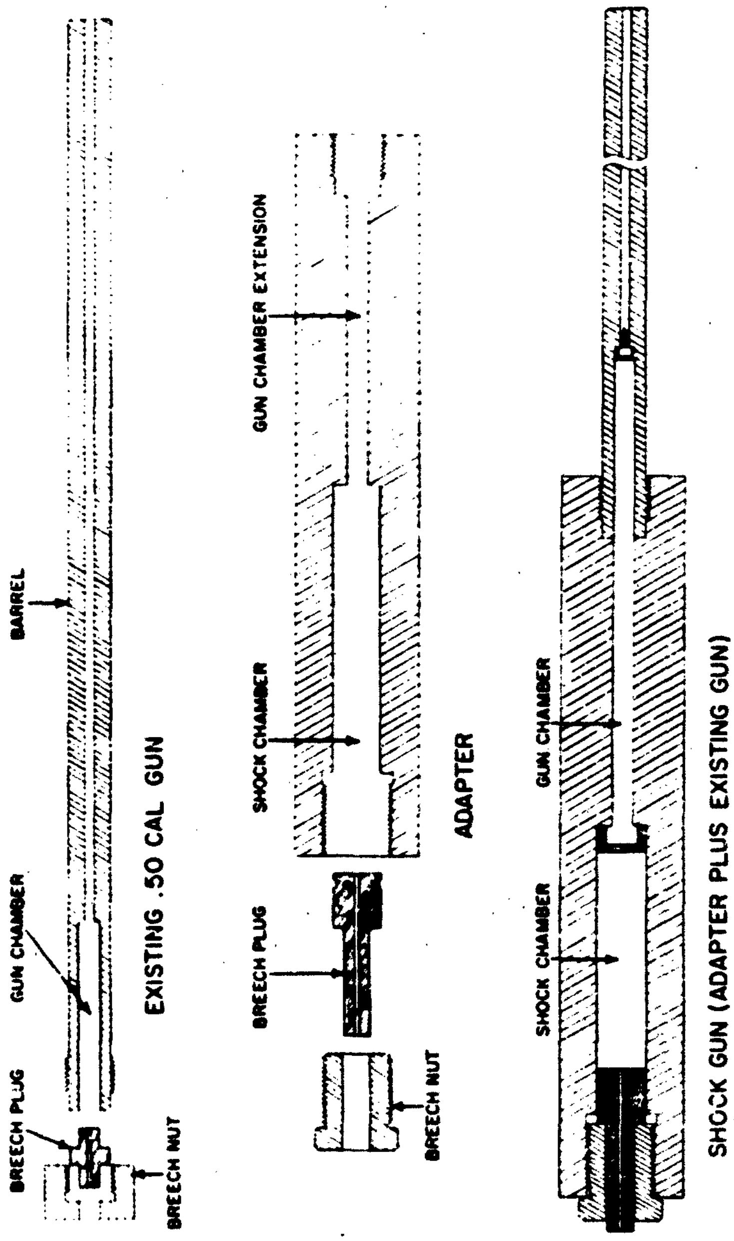

BARREL
GUN CHAMBER
BREECH PLUG
BREECH NUT
EXISTING .50 CAL GUN
GUN CHAMBER EXTENSION
SHOCK CHAMBER
BREECH PLUG
BREECH NUT
ADAPTER
GUN CHAMBER
SHOCK CHAMBER
SHOCK GUN (ADAPTER PLUS EXISTING GUN)

FIG. 2

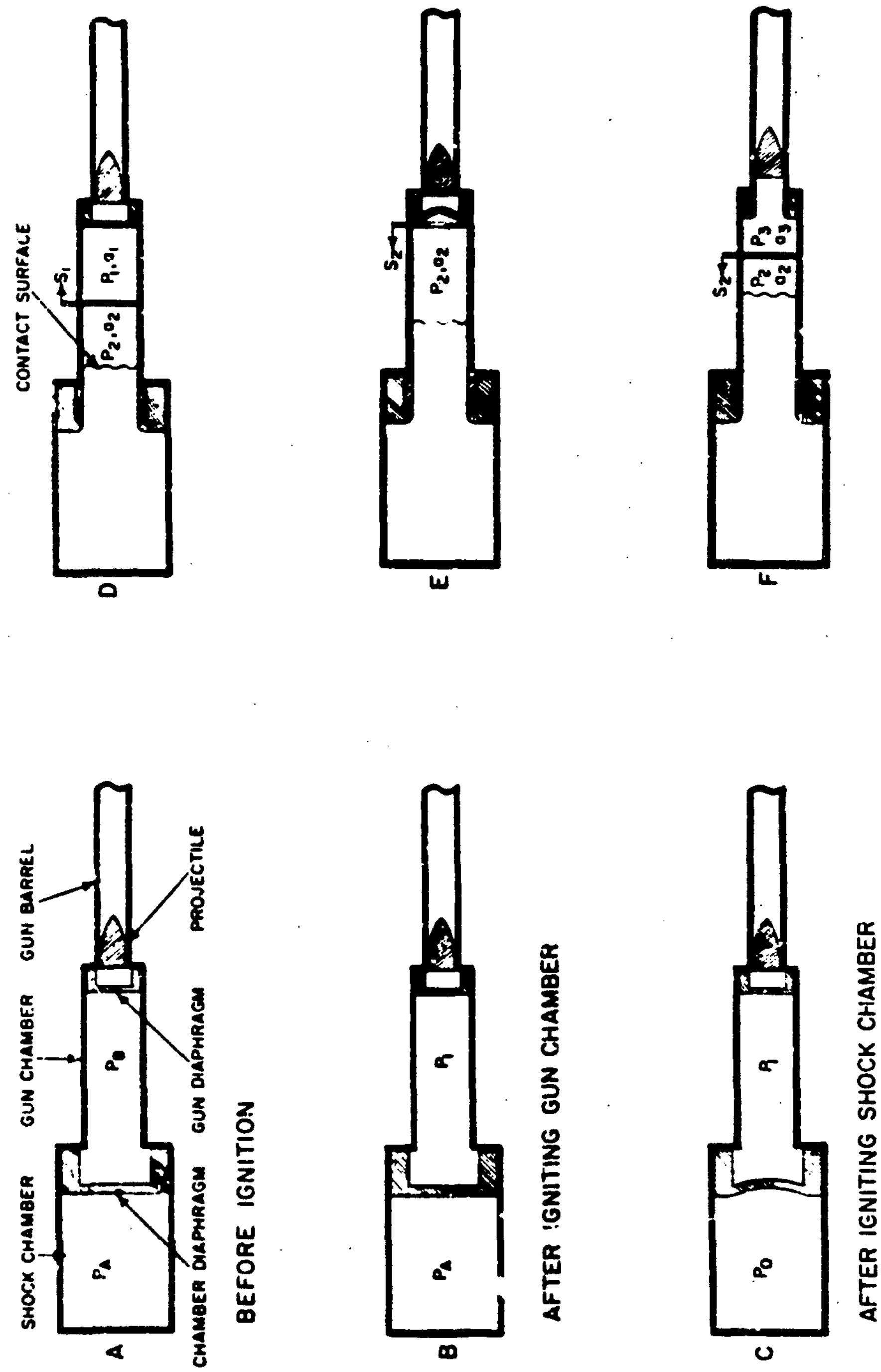

CONTACT SURFACE
S_1
P_1, a_1
P_2, a_2
D
S_2
P_2, a_2
E
S_2
P_2 a_2
P_3 a_3
F
GUN BARREL
PROJECTILE
GUN CHAMBER
P_B
GUN DIAPHRAGM
SHOCK CHAMBER
P_A
CHAMBER DIAPHRAGM
A
BEFORE IGNITION
P_1
P_A
B
AFTER IGNITING GUN CHAMBER
P_1
P_0
C
AFTER IGNITING SHOCK CHAMBER

FIG. 3

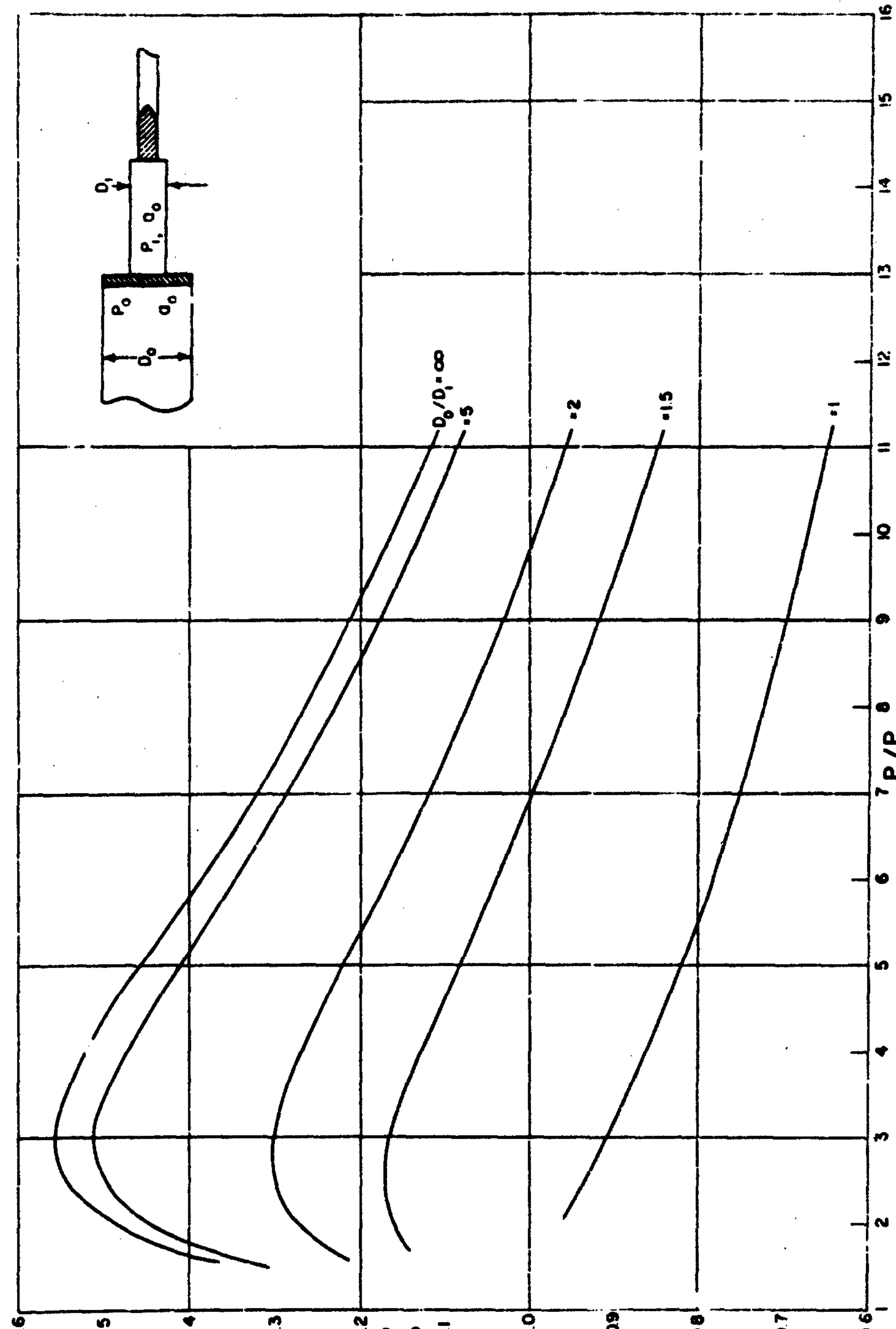


FIG. 4 PRESSURE OF GAS AFTER PASSAGE OF REFLECTED SHOCK

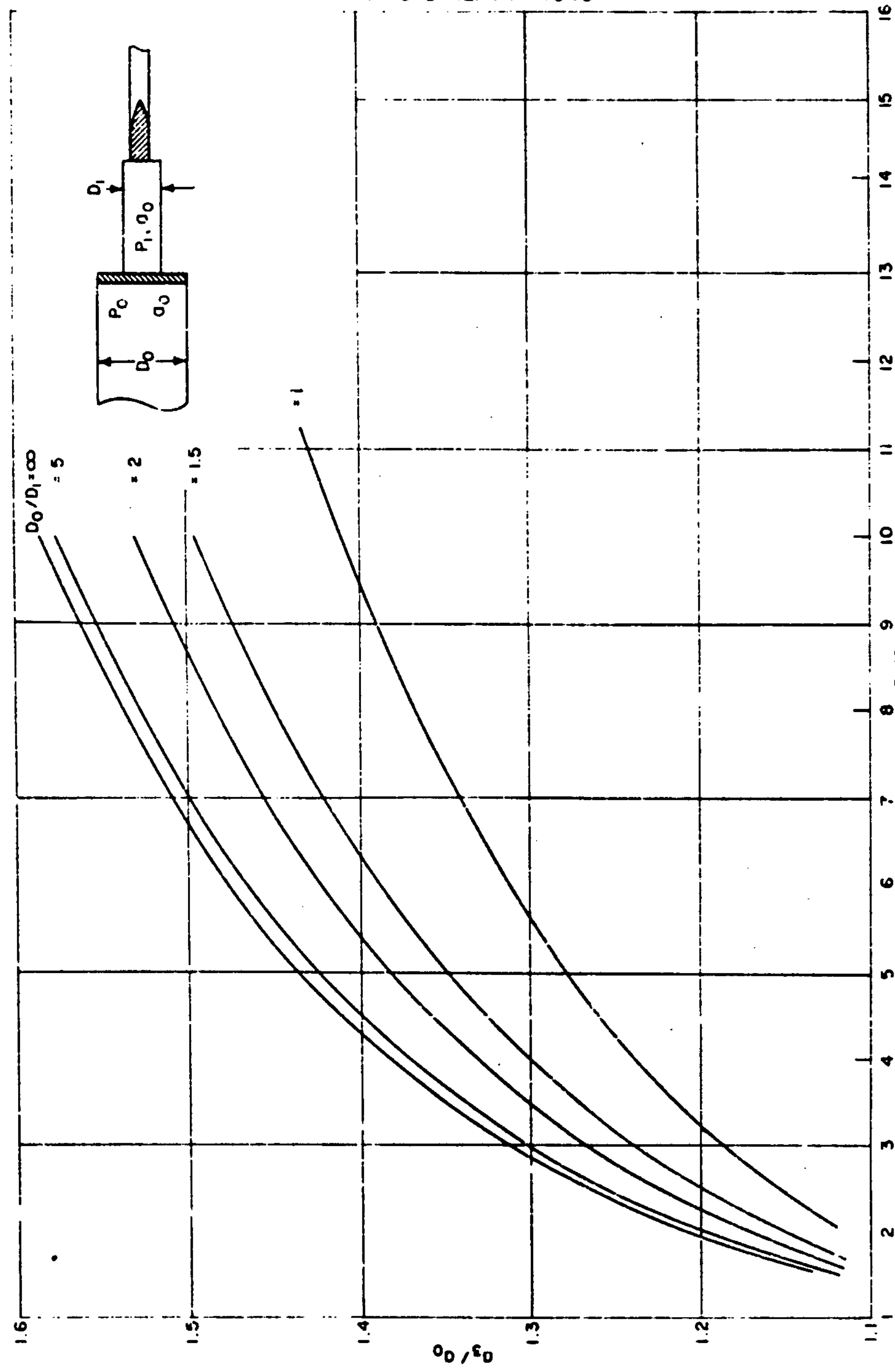


FIG.5 SOUND VELOCITY OF GAS AFTER PASSAGE OF REFLECTED SHOCK

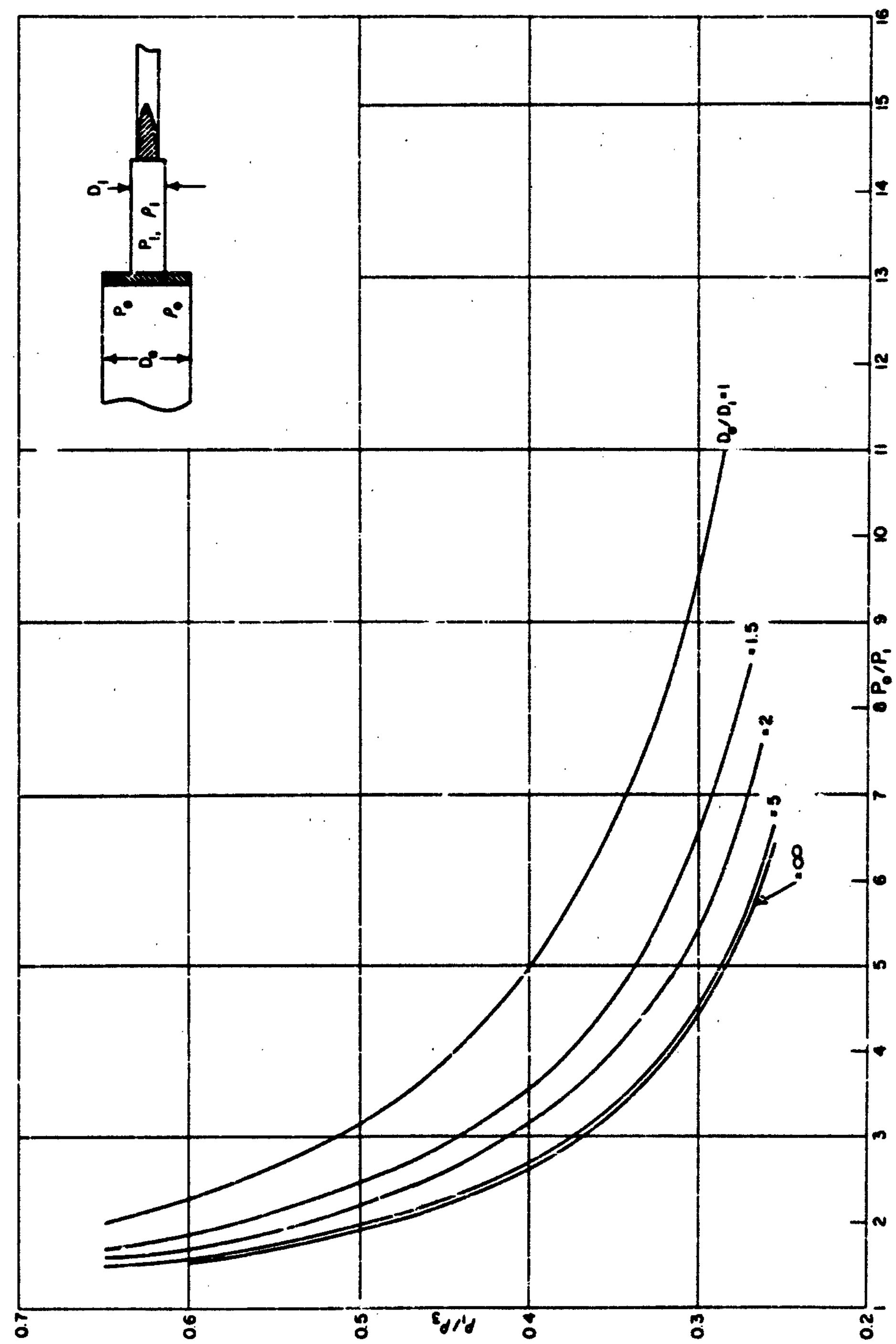


FIG. 6 DENSITY RATIO OF GAS AFTER PASSAGE OF REFLECTED SHOCK

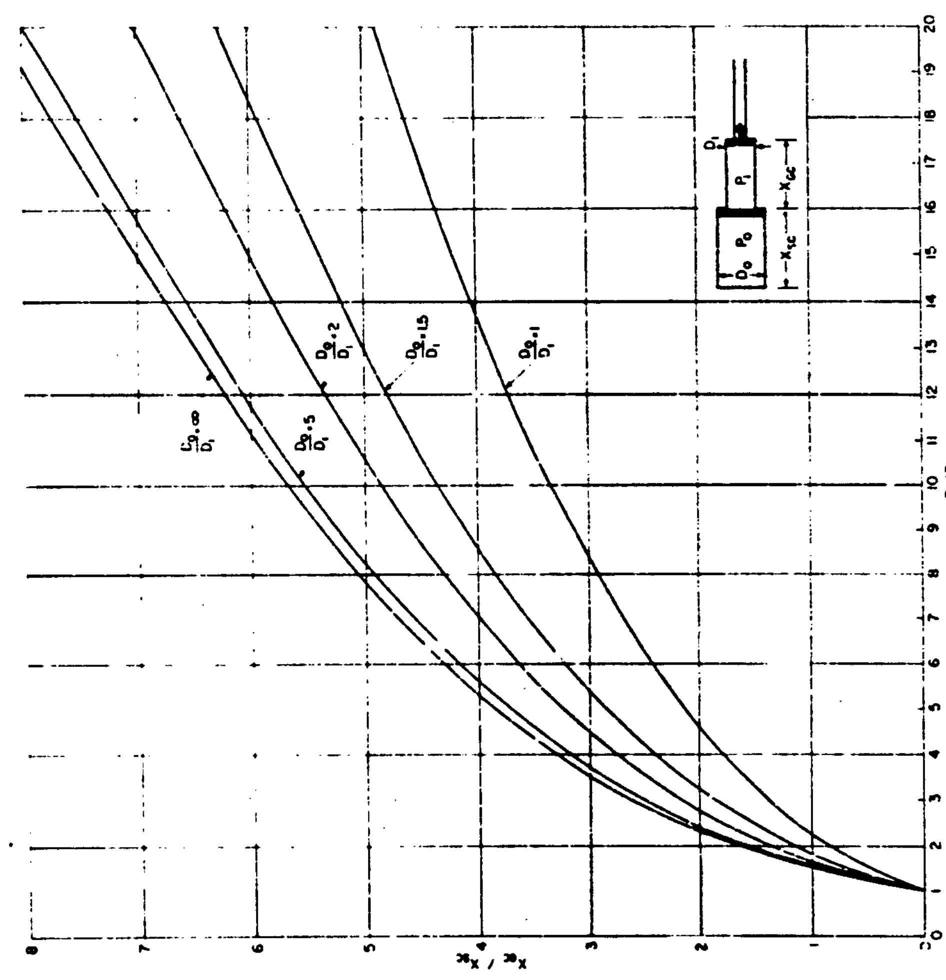


FIG. 7 NECESSARY RATIO OF GUN CHAMBER LENGTH TO SHOCK CHAMBER LENGTH

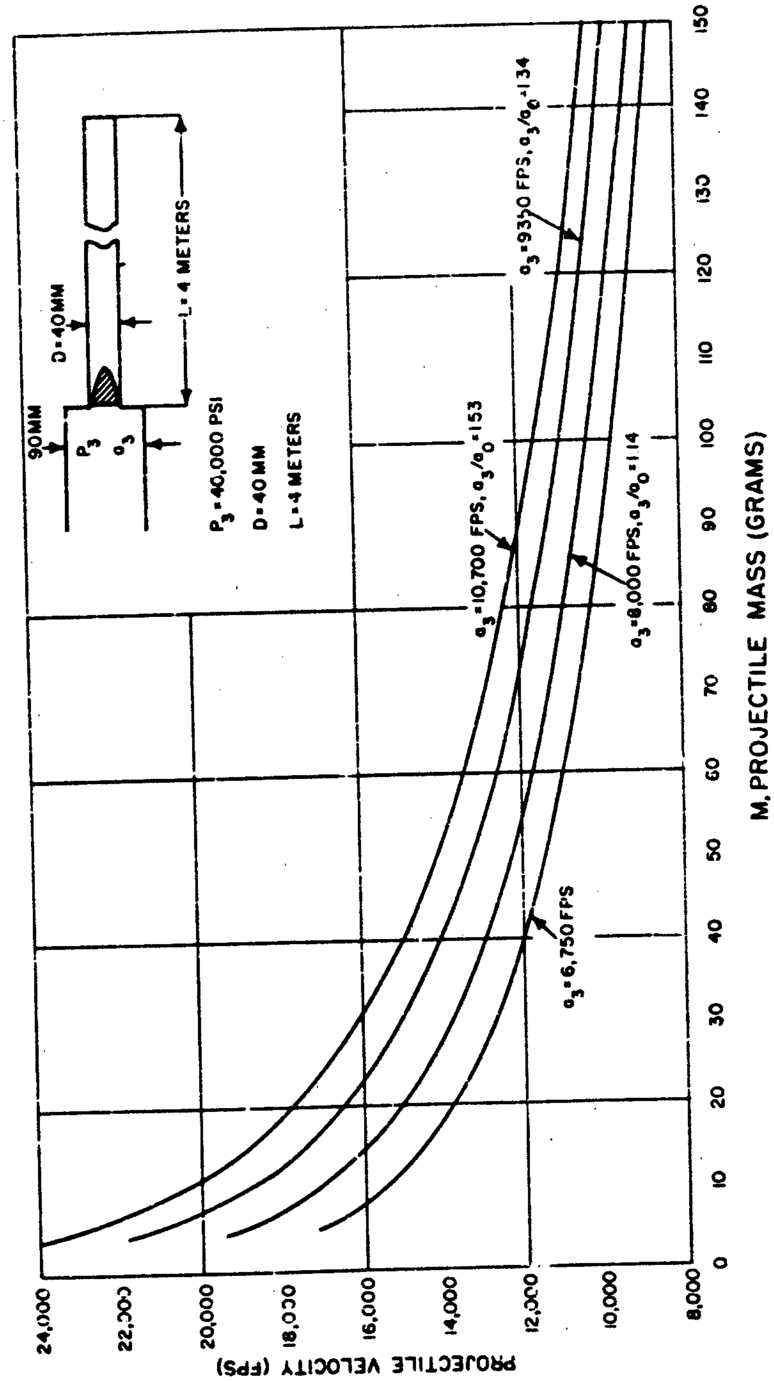


FIG. 8 40 MM SHOCK GUN PERFORMANCE

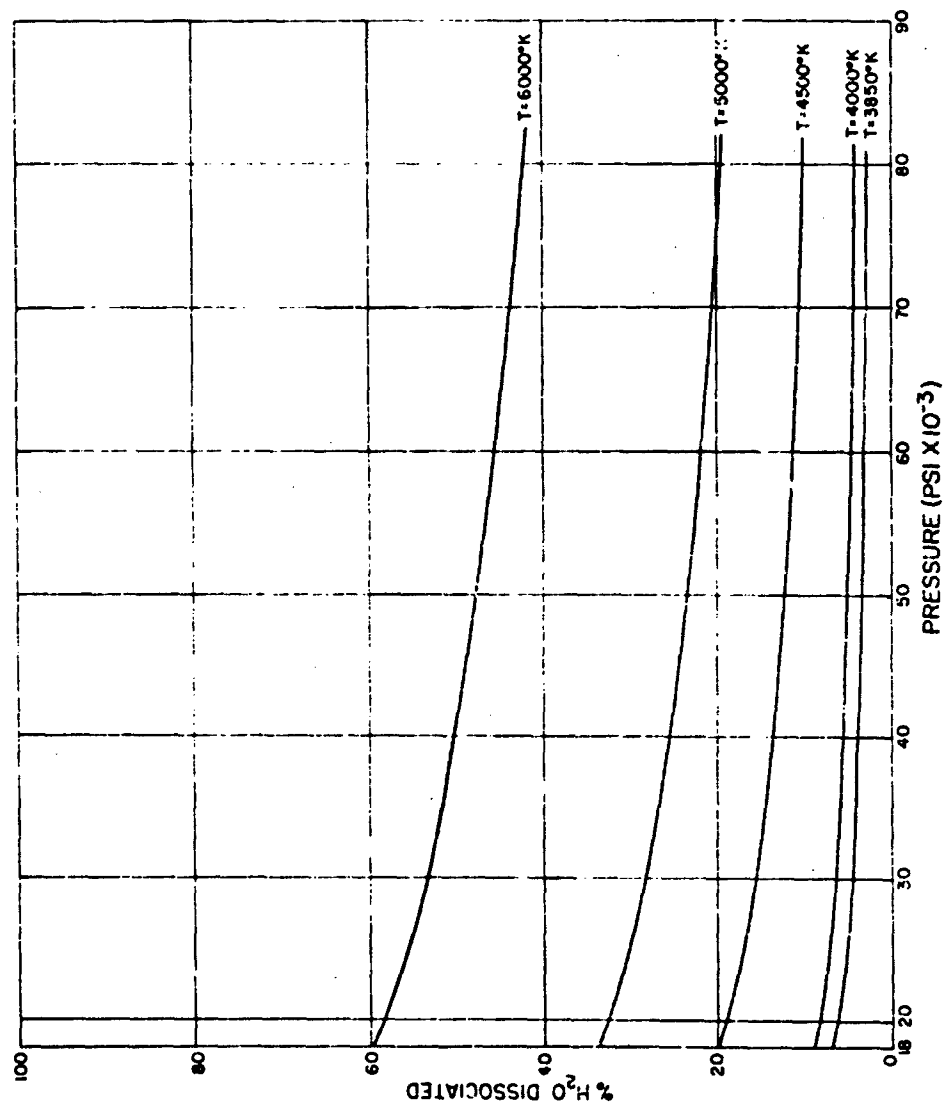


FIG 9 % DISSOCIATION OF WATER IN THE REACTED MIXTURE

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